

Corrosion and the Choice of Metals for Cage Construction¹

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The problem of corrosion as it affects the life of animal cages and equipment is of great concern to investigators and personnel interested in animal care. This paper presents the characteristics of metals commonly used in cage construction, discusses life expectancy of metal cages and excreta pans as reported by over 100 laboratories, and reviews preventive maintenance and corrective procedures to combat and retard corrosion.

INTRODUCTION

It has been estimated that our country sustains an annual loss of seven billion dollars due to corrosion (estimated by the National Association of Corrosion Engineers), but much of this loss could be eliminated by the proper choice of metals and preventive maintenance procedures. To those interested in the use of animals for research programs, corrosion is evidenced by premature failure of equipment, unsightly appearance of cages and contamination of metabolic investigations. A retardation of these effects can only be achieved through an understanding of the reactions of a metal to its environment.

The following discussion is limited to a consideration of the corrosive characteristics of the three metals most commonly used in laboratory cage construction — stainless steel, galvanized steel and aluminum.

I. Characteristics of Corrosion

A. Stainless Steel

Only with reservations do metallurgists use the word "stainless" to designate the steel under discussion. Yet the word has become accepted terminology because the public has found that stainless does have

desirable corrosion-resistant characteristics.

The generally accepted theory that stainless steel obtains this corrosion resistance from an inert, self-healing "oxide film" forming over and protecting the metallic surface is useful and well supported. Very thin oxide films have actually been isolated or separated from the surface of stainless steel. If this protective film is damaged and not permitted to restore itself, corrosion may take place. Usually corrosion occurs in crevices or between contacting surfaces due to the inaccessibility of the necessary oxidizing agent required to restore the protective film. Corrosion may also take place in heat affected zones owing to the welding processes, for the high heat involved robs the alloy of some of its chromium content. Stainless steel is also subjected to chemical attack, usually in the presence of chlorides, other chlorine compounds and sulfur dioxide where moisture is present.

B. Galvanized Steel

The value of a metallic coating is its ability to resist corrosion more effectively than the base metal to which it is applied. Among the commercial coatings, zinc is the most widely used. The U.S. Bureau of Standards, Circular No. 80, states that zinc in the form of galvanizing is "by far the best" protective metallic coating for the rust-proofing of iron or steel. Not only does zinc serve as a barrier to seal out corrosive moisture but it also protects, if the base metal is exposed, through galvanic action, sacrificing itself slowly in the course of saving the base metal from rust. The conventional method of coating, known as Galvanizing, is the process that is used to pass the thoroughly cleaned metal through a bath of molten zinc. White rust is the first visible sign that the zinc coating is corroding. If a heavy zinc-iron layer is present and corrosion progresses to this

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alloy the color of the white rust turns a slight yellow. When the base metal is reached, the rust becomes reddish-brown indicating that all of the zinc has been removed and no protection from corrosion remains at this point.

C. Aluminum

As in stainless steel, the corrosion resistance of aluminum alloys depends on the presence of a very thin oxide film that protects the metal surface. This film is capable of repairing itself, if damaged by chemical action, provided there is sufficient oxygen present in the environment. Although there are other types of corrosion affecting aluminum, such as galvanic and metallurgic, the one usually encountered in animal cages and excreta pans is of chemical origin. Caustic alkaline cleansers containing lye and phosphates seem to destroy the protective oxide film and lead to the progressive deterioration of the metal.

II. Corrosion and the Final Choice

The effects of corrosion present a problem so obvious and pressing, that it frequently overshadows other important factors in metal selection. When all things are considered, a metal with a somewhat higher rate of corrosion may be better choice than one with a lower rate due to the important contributory effects of other chemical and physical factors. The following are some of the factors that influence the choice of a metal or alloy for cage construction:

1. Availability in the required shapes and sizes.
2. Amenability to fabrication by standard methods.
3. Ability to withstand the physical stresses of normal service.
4. Resistance to corrosion.
5. Effects on the investigations' measurements during experimental procedures.
6. The cost of the equipment relative to the duration of the program.

We will use these six points to evaluate the three metals under discussion. Stainless steel, galvanized steel and aluminum are all available in the various forms required for cage construction such as sheets,

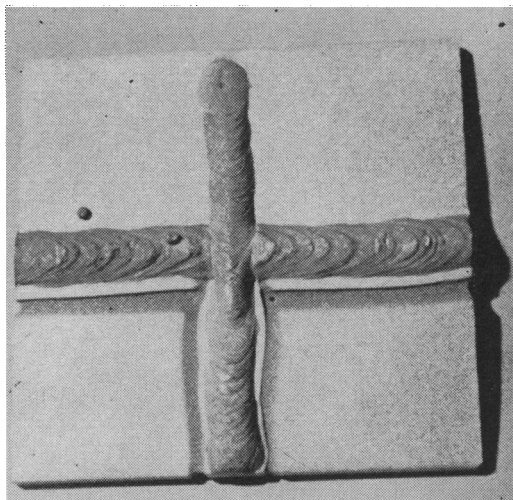


Figure 1. Intergranular corrosion of stainless steel. The corrosion free plate in the upper part of the photo is of low carbon, Type 304 stainless steel, whereas the lower plate, showing heavy concentration of intergranular, weld corrosion is of Type 302 stainless steel.

wire cloth, bars, rods and hardware. Variations, however, occur in appraising these metals with respect to the other five points.

A. Stainless Steel

Stainless steel lends itself to standard fabrication methods such as blanking, forming, bending, soldering and welding. The greatest difficulty is experienced in maintaining corrosion resistance due to the stresses and changes in the crystalline structure that are created by welding processes. Thus, while the type of stainless steel used commonly for cage construction is Type 302, Type 304 should be specified where a considerable amount of welding is involved, as it is less prone to weld decay.

Weld decay or intergranular corrosion (Figure 1) can begin along the weld boundaries owing to carbide precipitation. Carbon residue that is created in the course of mill processing will migrate to the grain boundaries during welding, and will be precipitated to these areas as chromium carbide particles. The removal of valuable chromium immediately adjacent to the boundaries depletes these areas of the chromium that is required to maintain corrosion resistance.

There are several ways to reduce or eliminate this type of corrosion, one of which is to use the low carbon, Type 304, stainless steel in order to improve limita-

tions upon the quantity of this element that could migrate to the grain boundaries. Other methods include heat treating or annealing after welding and the use of special stabilized grades of stainless steel containing columbium, tantalum and titanium, each having a stronger affinity for carbon than chromium.

The high temperatures attained during welding usually develop surface scale that must be removed. General scale and oxide can be removed by shot, grit or sand-blasting, wire brushing (with stainless steel brushes) or grinding. This should be followed by a passivating process consisting of cleaning the disturbed surface of the stainless steel with a 10 to 20 per cent solution of nitric acid. A thorough rinsing in clean, hot water to remove all traces of the acid solution will hasten the formation of the passive oxide film on the surface of the stainless steel.

One type of stainless steel used erroneously for cage construction, in the belief that all types have the same corrosion resistance, is designated as Type 430. The absence of nickel in this alloy greatly increases the tendency to develop superficial rusting along the weld joints. Also, Type 430 is more susceptible to contact and crevice corrosion than Type 302. A quick check with a magnet can be made to differentiate Types 302 and 304 from the straight chromium grade, Type 430. The latter is magnetic while the former are not.

Chromium-nickel stainless steels, such as Types 302 and 304, have high tensile strength, that is, they have toughness and are able to withstand the mechanical abuse of handling and sterilizing. Their resistance to corrosion is well known as evidenced by reports received from more than 100 laboratories. One laboratory test on record states that the corrosion rate of Type 304 is less than 0.42 mils per year in uric acids at room temperature (Huston, 1958). The report, however, did not state the acid concentration nor the duration of the test.

The last in our list of factors used for evaluating metals for cage construction is the most detrimental to stainless steel. The basic cost of stainless steel is roughly five times that of galvanized steel. Fabrication costs are also higher due to the greater care required in handling, and the accelerated rate of wear on tools and dies.

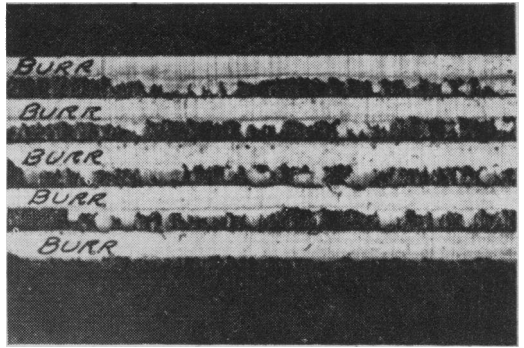


Figure 2. Photomicrograph of sheared edges of galvanized steel. Cross section of five sheets of No. 20 gauge, zinc grip, galvanized steel showing the sheared edges under seven magnifications. Note the zinc that has been dragged over these edges during the shearing action.

An investigator, knowing the length of his program, must choose between all galvanized steel, galvanized cages with stainless steel pans and all stainless steel equipment. Often the first or second choice will outlast the need for that particular type of animal housing. In addition, one other pertinent factor must be considered — that of obsolescence. Owing to the high cost of 100 per cent stainless steel equipment, it is not economical to "charge off" or scrap this type in 10 to 15 years, even though conditions have changed to affect more advanced methods for housing and servicing research animals.

B. Galvanized Steel

1. PRE-DIPPED COATINGS

Galvanized steel's amenability to standard fabrication methods has been well established for many years. The soft zinc coating drags over sheared edges and perforations in steel of No. 20 gauge and thinner sheets (Figure 2). This drag plus galvanic protection are effective in sealing these surfaces from corrosive attack. The basic steel substrate provides the structural strength necessary to withstand the abuse of handling and rough treatment that may occur incidental to the cleaning and sterilizing procedures. Since welding methods disturb and burn the zinc coating around the area of weldment, it is advisable to recoat this area with a zinc-rich or other rust inhibitor coating.

The degree of corrosion resistance is somewhat controversial as evidenced by the reports received from various laboratories to be quantitatively discussed later in this paper. Zinc coatings have good re-

sistance to the alkalis normally used in cleaning and sanitizing methods but are attacked by acids, including those found in animal urines. The variance in reports undoubtedly were due to the employment of non-uniform cleaning methods. Frequent cleanings, for instance, controlled or retarded the attack of urine acids. On the other hand, the use of steel brushes accompanied by inadequate drying, accelerated corrosion on the abraded surfaces.

Since zinc is anodic to stainless steel in galvanic action, the use of these materials in compound construction such as galvanized wire mesh floors locked into stainless steel seams, is not recommended. This is not a factor, however, when the floors are removable thereby permitting frequent cleaning and drying. Since the cost of galvanized steel cages is the least expensive of the corrosion-resistant metals under discussion, its use is favored in most vivariums.

2. POST-DIPPED COATINGS

Post-dipped zinc coatings or hot dipped galvanized coatings after fabrication have certain desirable attributes not inherent to the commercial pre-dipped steel. In the first place, the thickness of the coating is more than twice that of the pre-dipped coatings, and since the corrosion resistance of the final product is directly proportional to the amount of zinc deposited, its corrosion free life is doubled. Secondly, the molten zinc flows over all weldments, fills internal corners and seals crevices. This would seem to be an ideal coating for all applications but unfortunately such is not the case. The hot dip method involves the immersion of the cage into 860 F, molten zinc. This heat and the stresses set up due to temperature changes, warp and distort cages fabricated of comparatively thin gauges and large flat surfaces such as shelving, because they have less structural rigidity.

C. Electro-zinc Coated Steel

In some instances it is necessary to electro-deposit zinc and cadmium coatings on steel parts such as hardware and casters for corrosion resistance. This is only recommended in cases where the warping characteristic of the hot dip method is impractical, for the electro-deposited coat-

ing is approximately one-fourth of the thickness of commercial quality pre-dipped galvanized steel.

D. Aluminum

Aluminum is easily formed, being comparatively soft, but does not lend itself to the common methods of joining such as controlled arc and resistance welding, with the kind of equipment that is normally found in metal fabricating plants which do not specialize in aluminum products. The point at which fusion is effected in resistance welding of aluminum is so critical that factors such as variations in line voltages, pressure of electrodes, time cycles and surface contaminants will prevent good weldments. Controlled arc-welding by the shielded inert gaseous method is very effective but is restricted to gauges of aluminum heavier than normally used for cage construction, as the high degree of heat melts apart rather than fuses together the adjacent metal edges. This material lacks the ability to withstand the physical stresses of normal service since the high ductility that facilitates formability, also permits deformation. It is comparatively easily scratched and gnawed by rodents. There is some evidence that vitamin deficient rodents are attracted to the residual oils left from the mill's processing procedures. All mills, however, insist the processing oils are of mineral content, without nutritional value. Although two of the mills admitted knowledge of the tendency for rodents to gnaw upon aluminum, they thought it to be a matter of tooth development, tooth sharpening, or more likely, an attempt to gain freedom. In some fabrication processes, however, such as spinning, a tallow or lard is used as a lubricant between the metal and the forming tool. The residual oils thus left will attract vitamin deficient rodents. This can be overcome with some degree of success by heat treating, not only to bake out the residuals but also to temper the aluminum approaching the hardness of steel. While aluminum has excellent corrosion resistance to water and uric acids, it is susceptible to the alkaline solutions normally found in proprietary cleansers. Another disadvantage is the price, which is more costly than galvanized steel without having the structural advantages of the latter nor the corrosion resistance qualities of stainless steel.

III. Average Life of Cages as Reported by 104 Laboratories

Due to the lack of documented material concerning the expected life of animal cages, an attempt was made to quantitatively correlate species of animals and the method of cleaning to the rate of corrosion of various metals by mailing 1800 questionnaires to large and small laboratories. The thoroughness with which the 104 of the questionnaires returned were completed permitted the following evaluation.

The majority of those reporting emphasized a direct correlation between species of animal housed and the rate of corrosion of the galvanized excreta pans (Figure 3). The differences noted in species rating, through a point valuation system with No. 1 indicating most rapid rate of corrosion were as follows: The rabbit had top score of 1.56, followed by the guinea pig with 2.49; mouse, 3.5; rat, 3.7; cat, 4; monkey, 4.37; dog, 4.4; and the hamster with a high of 6.14 indicating little effect on corrosion. The rabbit's habit of defecating in cage corners and its large amount of liquid discharge is known, but another contributory effect to the high corrosive rate of the rabbit's urine may be in the diet. While a normal herbivorous diet produces slightly alkaline urine, oats, an ingredient of most pellet feed, renders the urine acid (Blount, 1957). Galvanized steel, as previously mentioned has good corrosive resistance to alkalies but not to acids.

Attempts to correlate cage washing procedures to corrosion rate was practically impossible owing to the great variation in procedural applications. For instance, frequency of cage washing varied from daily to monthly, and methods of cleaning ranged from hand brushing to automatic processes using proprietary cleansers of over 30 varieties usually of a highly alkaline composition. Human factors such as abuse in handling, abrasive materials used in cleaning such as steel wool and steel brushes, plus a consistent lack of thorough drying of cages, also affected cage longevity.

The laboratories using stainless steel cages reported "no wear" or "no corrosion" since their original purchase for periods varying from 3 to 10 years. Many reported anticipated longevity of stainless cages as "lifetime" or "indefinite." The life of

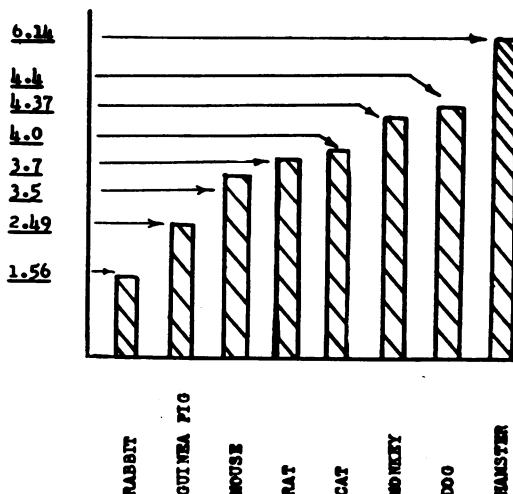


Figure 3. Relationship of animal species to rate of corrosion. With No. 1 indicating most rapid rate of corrosion this bar graph shows the comparative effect of animal species on cage and excreta pan corrosion as gleaned from 104 reporting laboratories.

galvanized excreta pans and cages varied considerably owing to local variations previously mentioned with pre-dipped or galvanized steel excreta pans varying from two to ten years, although the major portion of the reports referred to a two to three year life span. Pre-dipped galvanized cages varied from two to 25 years in life with the average being in the eight to 15 year range. Cages, post-dipped or galvanized after fabrication, showed increased life, as was to be expected, with the minimum reported as ten years — others up to 25 years. The average ranged in the ten to 20 year bracket.

IV. Preventive Maintenance Procedures To Retard Corrosion

A. Stainless Steel

The importance of cleaning stainless steel cannot be over-emphasized in maintaining appearance and prolonging life. Salt solutions, disinfectants, bleaches or cleaning compounds should not be allowed to remain in contact with stainless steels for extended periods. Many of these compounds contain chemicals such as chlorine which could be harmful. Steel wool or steel brushes should not be used for small bits of steel may adhere to the surface causing rust. If it is necessary to use metal brushes, the bristles should be made of one of the Type 300 series of stainless steel. Nor-

	Availability in Required Forms	Ease of Fabrication	Durability Under Normal Service	Resistance to Corrosion	Effects on Investigations Measurements	Initial Cost
Stainless Steel	Good	Good	Good	Excellent	Susceptible to some Chemicals	High
Galvanized Steel	Good	Good	Good	Good	Susceptible to acids	Compar- atively low
Aluminum	Good	Difficult to weld in thin gauges	Fair	Excellent	Susceptible to alkaline solutions	High

Figure 4. Chart recapping the advantages and disadvantages of the metals discussed.

mally, hot water with mild soap is all that is needed for cleaning, followed by a clear water rinse. If, however, the oxide film protecting the stainless steel should be destroyed and rust evidenced, cleaning can be accomplished by the use of a phosphate cleanser, such as tetradodium pyrophosphate. The stainless steel will then passivate itself upon exposure to air.

B. Aluminum

Previous mention was made of the corrosion resistance of aluminum being derived from a protective oxide film. Although the natural film is only approximately 0.0000005 inch thick, it can be increased more than 600 times this thickness by an electrolytic process called anodizing. A resultant increase in corrosion resistance is realized.

To reduce the attack of strong alkaline cleansers on aluminum, an inhibited cleanser should be used in the cage washing process. This non-caustic type has a silicate additive that leaves a protective coating on the aluminum.

C. Galvanized Steel

Since zinc corrodes slowly in protecting the substrate steel from corrosion with

deterioration accelerated by chemical and abrasive wear, red rust will eventually be evidenced. Proper maintenance procedures in recoating the equipment before oxidation becomes too advanced will greatly extend its useful life.

Paint coatings fall into two classifications — metallic and organic. Of the former, zinc and aluminum are most widely used. Aluminum pigment, being in the form of flakes instead of granules, forms a hard laminated surface, 5 to 10 flakes high, that is impervious to water, has excellent radiant heat reflectivity but does not withstand the attack of cleansers with a strong alkali content. Many of the so-called neutral cleansers have a chlorinated compound whose directions for use state, "injurious to aluminum." These products will also attack stainless steel.

There is a growing interest and enthusiasm for a new type of zinc-rich paint formulated with 95 per cent zinc dust content. Zinc dust paints are fundamentally suitable for use on galvanized steel because of their unusual adherence to the coating of zinc. If, however, rust has reached the advanced stage, it is advisable to remove the loose surface scale by chem-

ical means before applying any restorative coating, because rust particles may produce paint blisters and eventually fracture the coating. Proprietary chemical cleaners to remove rust are available from any paint supplier.

With respect to organic coatings, the vinyls and epoxy resins give the most promise. These coatings are tough, flexible and resistant to oxidation. They combine the characteristics of chemical resistance with the properties of baked on enamel. It would be interesting to have these coatings field checked under controlled conditions to ascertain the extent of their ability to withstand the abuse normally subjected to animal cage equipment.

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New Products

REFERENCE "FINDER" FOR USE IN MICROSCOPY

This new "Finder" has been designed to provide an accurate reference system whereby the user of a microscope and slide mounted specimens can be sure of easily and quickly

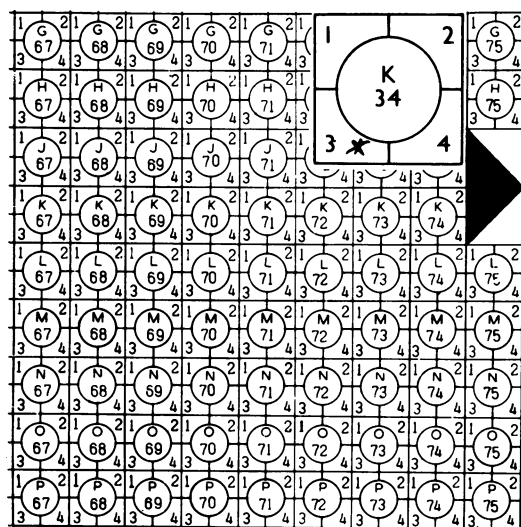
finding the field of interest.

The system is simple as the illustration shows and may be likened to a grid for map users.

Use of this "Finder" is simple. The specimen slide is placed on the stage of the microscope and the bottom long edge is brought into contact with the base stops of the stage and then slid either to the left or right, into contact with the vertical fixed stops, as necessary.

After examining the specimen in the normal way and finding a point of interest it is brought to the centre of the field of view, then, taking care not to alter the position of the fixed stops of the stage, the slide is removed and replaced by the England "Finder", again bringing the bottom edge in contact first and sliding to the appropriate vertical stop, the label of the "Finder" being at the bottom left corner. The reference pattern of the "Finder" can now be seen through the microscope.

Further details of this "Finder" and the self adhesive labels may be obtained from Graticules Ltd., 57-60, Holborn Viaduct, London, E.C.1., England.



Enlarged portion of England "Finder" with indicating arrow at side.
(Inset) Point of interest marked with cross in third segment.